FERMILAB-CONF-07-156-E

Searching for $H \to WW^*$ and Other Di-boson Final States at CDF

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We report a search for standard model (SM) production of a Higgs boson which decays to WW^* in two charged leptons (e,μ) and two neutrino final state in $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV. The data were collected with the CDF II detector at the Fermilab Tevatron and correspond to an integrated luminosity of 1.1 fb^{-1}. The Matrix Element method is used to calculate the event probability and to construct a likelihood ratio discriminator. The observed(the median of the expected) 95% Confidence Level (CL) upper limit for $\sigma(H \to WW^*)$ with 160 GeV/c^2 mass hypothesis is 1.3(1.8) pb which is 3.4(4.8) times the SM prediction at next-to-next-to-leading logarithmic level (NNLL) calculation.[1] The SM ZZ production search is performed in the same final states. The observed significance is 1.9 σ and the 95% CL upper limit is 3.4 pb which is consistent with the next-to-leading order(NLO) calculation of 1.4 ± 0.1 pb[2].

1 Introduction

The Higgs boson is introduced into the standard model (SM) to explain the electroweak symmetry breaking and the origins of particle mass. The 95% CL interval on the Higgs mass is constrained to be 114-182 GeV/c^2 with the current precision electroweak measurements[3]. We search for the Higgs through gluon fusion production channel, $gg \to H \to WW^*$, which is the dominant channel for Higgs $m_H > 135$ GeV/c^2. The maximum NNLL Higgs production cross section is $\sigma(p\bar{p} \to H \to WW^*) = 0.388$ pb for $m_H = 160$ GeV/c^2. This is a small signal compared to the SM WW production with NLO cross section 12.4 pb. A good understanding of the SM diboson production is essential for this search. To get a good signal to background ratio sample, we search for fully leptonic decay of $WW^* \to l^+l^-\nu\bar{\nu}$, where $l^\pm$ = e, μ or τ and τ decays to e or μ. The ZZ could decay to the same final states and it has not yet been observed at $p\bar{p}$ colliders. The analysis strategy is to maximize the signal acceptance by loosing selection cuts and use the likelihood ratio discriminator(LR) calculated by Matrix Element methods to set the statistical limits for 10 different Higgs mass hypothesis. The search for ZZ production is done in the same way but considering ZZ as signal and no Higgs contribution.

2 Selection

The $l^+l^-\nu\bar{\nu}$ candidates are selected from two opposite-sign leptons from the same vertex and high missing transverse energy $\not\!\!E_T$. At least one lepton is required to satisfy the trigger and have $p_T > 20$ GeV/c. The other lepton has looser requirement $p_T > 10$ GeV/c to increase the kinematic acceptance. To suppress the significant backgrounds from $W\gamma$ and W+jets where γ conversions to electrons or a jet is mis-constructed as a lepton, we require leptons to be both energy and track isolated such that the sum of the $E_T(p_T)$ for the calorimeter towers (tracks) in a cone of $\Delta R = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2} < 0.4$ around the lepton is less than 10% of the E_T for electrons or p_T for muons and track lepton candidates. To suppress the Drell-Yan background, we require $\min \not\!\!E_{T,\mathrm{rel}} > 25$ GeV, where $\min \not\!\!E_{T,\mathrm{rel}}$ is defined to be:

$$\min \not\!\!E_{T,\mathrm{rel}} \equiv \begin{cases} \not\!\!E_T & \text{if } \Delta\phi(\not\!\!E_T, \mathrm{lepton}, \mathrm{jet}) > \frac{\pi}{2} \\ \not\!\!E_T \sin(\Delta\phi(\not\!\!E_T, \mathrm{lepton}, \mathrm{jet})) & \text{if } \Delta\phi(\not\!\!E_T, \mathrm{lepton}, \mathrm{jet}) < \frac{\pi}{2} \end{cases} \tag{1}$$

This definition will reject the events whose $\not\!\!E_T$ just comes from single lepton or jet. We further require the candidates to have less than 2 jets with $p_T > 15$ GeV and $|\eta| < 2.5$, in order to suppress $t\bar{t}$ backgrounds, $M_{\ell^+\ell^-} > 25$ GeV in order to suppress heavy flavor contributions, and exactly 2 leptons to suppress WZ contributions with a third lepton.

For ZZ analysis, the $e\mu$ channel is not used and one addition cut, $\not\!\!E_{T,\mathrm{sig}} \equiv \not\!\!E_T \sqrt{\sum E_T} > 2.5$ GeV$^{\frac{1}{2}}$, is applied to suppress the effect of mis-measurement of unclustered energy.

3 Event Probility Calculation

In order to use the maximum kinematic information to distinguish each modes, we use an event-by-event calculation of the probability density function $P_m(x_{obs})$ for a mode m which is either Higgs, WW, ZZ, $W\gamma$ or W+parton:

$$P_m(x_{obs}) = \frac{1}{<\sigma_m>} \int \frac{d\sigma_m^{th}(y)}{dy} \epsilon(y) G(x_{obs}, y) dy \tag{2}$$

where x_{obs} are the observed leptons four-vectors and $\vec{\not\!\!E}_T$, y are the true lepton four-vectors (include neutrinos), σ_m^{th} is the MCFM[2] leading-order theoretical calculation of the cross-section for mode m, $\epsilon(y)$ is total event efficiency $\times$ acceptance, $G(x_{obs}, y)$ is an analytic model of resolution effects, and $\frac{1}{<\sigma_m>}$ is the normalization. The function $\epsilon(y)$ describes the probabilities of a parton level object (e, μ, γ or parton) to be reconstructed as an observed lepton and is extracted by combinations of Mote Carlo and data. The event probability density functions are used to construct one dimensional discriminator:

$$LR(x_{obs}) \equiv \frac{P_H(x_{obs})}{P_H(x_{obs}) + \Sigma_i k_i P_i(x_{obs})}, \tag{3}$$

where H is Higgs, k_i is the expected fraction for each background and $\Sigma_i k_i = 1$. For SM ZZ search, we just use ZZ and WW to construct the discriminator.

4 Systematics

Table 1 summarizes the various systematics of each mode. The $\not\!\!E_T$ resolution modeling uncertainty, lepton selection scale factor and trigger efficiency are determined from comparisons of the data and the Monte Carlo simulation in a sample of dilepton events. The uncertainties are propagated through the analysis. For the $W\gamma$ background contribution, there is an additional uncertainty of 20% from the detector material description and conversion veto efficiency. The higher order effects in WW is assigned to be a half of the difference between the Pythia and MC@NLO[4] acceptance. The systematic uncertainty on the W+jets background is determined from differences between the measured probability that a jet is identified as a lepton for jets collected using different jet E_T trigger thresholds. An additional 6% uncertainty originating from the luminosity measurement is assigned to both signal and background except W+jets.

Table 1: The systematics for $l^+l^-\not{E}_T$ analysis. The numbers in the parenthesis are for the ZZ search.

	WW	WZ	ZZ	tt	DY	$W\gamma$	W+jets	Higgs
$\not{E}_T$ Modeling	1.0	1.0	1.0	1.0	20.0	1.0	-	1.0
Conversions	-	-	-	-	-	20.0	-	-
NLO Accept.	4.5(5.1)	10.0	10.0	10.0	5.0	10.0	-	10.0
Cross-section	10.0	10.0	10.0	15.0	5.0	10.0	-	-
PDF Uncert.	1.9	2.7	2.7	2.1	4.1	2.2	-	2.2
LepId $\pm 1\sigma$	1.5(1.4)	1.6(1.5)	1.5(1.5)	1.4(1.3)	1.8(2.2)	1.4(1.1)	-	1.5
Trigger Eff.	0.3	0.3	0.3	0.4	0.4	0.5(0.6)	-	0.3
Total	11.3(11.5)	14.5	14.5	18.2	21.7	24.7(24.6)	26.8(23.3)	10.4

5 $H \to WW^*$ Results

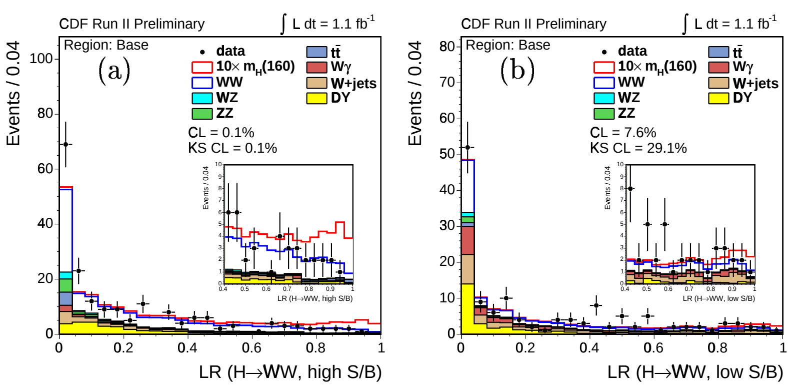

Figure 1: The LR distributions of Higgs mass 160 GeV/c^2 for (a) High S/B channel and (b) Low S/B channel.

	Expected
WW	132.9
WZ	9.5
ZZ	11.7
$t\bar{t}$	9.6
DY	55.4
$W\gamma$	24.7
W+jets	42.4
Total	286.1 ± 23.3
Data	323

Table 2: Expected and observed yields for $H \to WW$ selection.

The expected and observed yields of each modes are shown in Table 2 and Table 3. The LR distributions are shown in Fig 1 and all the candidates are cataloged into two channels based on the signal to background ratio (S/B) for each event. The limit of Higgs production cross section is evaluated by performing a Bayesian binned maximum likelihood fit. All of the background normalizations are free parameters in the fit but constrained to their expectations with a set of Gaussian constraints considering all of the assumed correlations between the systematics uncertainties. The limits of Higgs production cross section times WW^* decay branching ratio, $\sigma_{95\%}$, and their ratios to NNLL calculations (σ_{SM}) are shown in Table 3 and Figure 2.

6 ZZ Results

The expected and observed yields after the ZZ selection are shown in Table 4. The variable, $log_{10}(1 - LR)$, is used to set the upper limit and is shown in Fig 3. The Frequentist approach is used by performing background-only Monte Carlo experiments based on the expected yields varied within the assigned systematics. For each experiment a test statistic is formed from the difference in the log likelihood value with the background-only model and with the signal yield

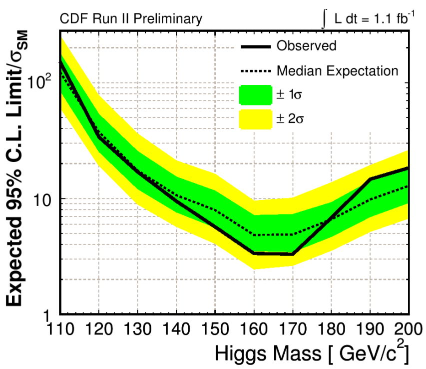

Figure 2: The ratio of 95% CL upper limit of $H \to WW^*$ production to NNLL calculation as a function of m_H.

	N_{exp}	$\sigma_{95\%}$(pb)	$\sigma_{95\%}/\sigma_{SM}$
110	0.2	8.9(7.1)	151.2(122.6)
120	0.6	4.7(4.9)	33.9(37.4)
130	1.4	4.0(3.8)	17.0(17.4)
140	2.4	3.0(3.4)	9.5(10.7)
150	3.2	2.1(2.9)	5.7(8.0)
160	3.9	1.3(1.8)	3.4(4.8)
170	3.9	1.2(1.7)	3.3(4.9)
180	3.3	1.9(1.8)	6.8(6.6)
190	2.4	2.8(1.9)	14.6(9.8)
200	2.0	2.8(2.0)	18.4(12.9)

Table 3: The expected yields, N_{exp}, and the observed (the median of the expected) 95% CL upper limit, $\sigma_{95\%}$, for the $H \to WW^*$ search.

at the best fit value. The observed significance is 1.9σ and we set the 95% CL upper limit of 3.4 pb, which is consistent with the SM NLO cross section of 1.4 ± 0.1 pb.

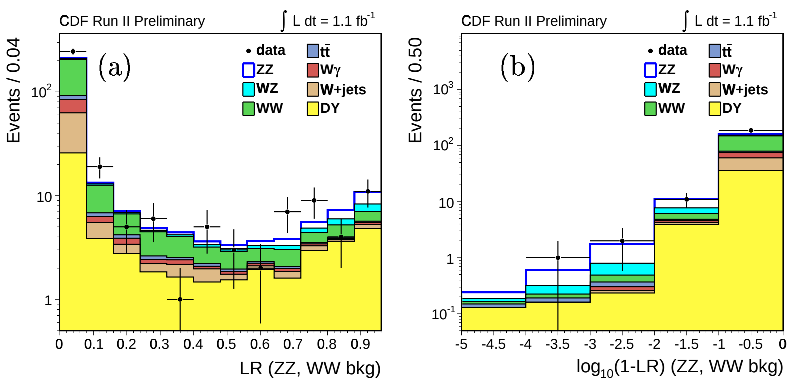

Figure 3: Distributions of (a) $LR = \frac{P_{ZZ}}{P_{ZZ}+P_{WW}}$ (b) $\log_{10}(1-\mathrm{LR})$

	Expected
WW	69.2
WZ	7.1
ZZ	10.7
$t\bar{t}$	5.1
DY	24.0
$W\gamma$	13.6
W+jets	23.2
Total	152.9 ± 11.6
Data	182

Table 4: Expected and observed yields for ZZ selection.

7 Summary

We have searched for a SM Higgs boson in the $l^+l^-\not{E}_T$ final state with the Matrix Element method. The observed 95% CL upper limit compares well with the expected upper limit as shown in Fig 2. We see no sign of a significant excess or deficit at any Higgs mass. The 95% CL upper limit for SM ZZ production is 3.4 pb and consistent with the SM NLO cacluation.

References

[1] S. Catani, D. de Florian, M. Grazzini, and P. Nason. *JHEP*, 07:028, 2003.

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[4] Stefano Frixione and Bryan R. Webber. *JHEP*, 06:029, 2002.